H. Butterfield — Man on his Past — Historiography

R.G. Collingwood — The Idea of History

H. Finberg (ed.) — Approaches to History
(R. Hall on Hist Science)

Distinguish Historiography — art (& science?) of writing history

Methods of History — collection of historiographical procedures.

5 views

1.) Pedagogicalism [?] — early 18th cent. history
2.) Fact-getting — 19th stage of positivism (Comte)
Ranke & Acton —
philological evaluation of sources —
external + internal evaluation.
3.) Relativism — general laws of history
cp. Marx, history as social science,
Toynbee etc.
4.) Empathetic history — Collingwood,
subjective problem situation
5.) Situational logic approach — Popper.

See also

P. Gardener (ed.) 1974
To Philosophy of History
(Oxford Readings in Philosophy)

Nagel: The Structure of Science ch 15.

HISTORY I

Greek Science (cp Cohen & Drabkin: A Source Bk in Greek Science)

Presocratic Speculative views of the nature of matter and the universe.

Hesiod / Homer — Mythos (myth) replaced by Logos (reason).

Ionian School (Miletus) — Thales (c624-565 BC) Everything made of water

Anaximenes (Ion c.570BC) . . . . air

Anaximander (611-547BC) Doctrine of the Apeiron.

Pythagoreans (b.c.582BC) number mysticism

Eleatic School (S. Italy) Parmenides (fl.504-492BC) change is illusory
Zeno (fl.464BC) (paradoxes to show that change and plurality are contradictory)

Heracleitus (c540-475 BC) Everything is in flux.

Sicily — **Empedocles** (c.500-c.430 BC) Earth air fire & water - irreducible elements.

from Ionia → Athens — **Anaxagoras** (478-428 BC) infinitesimal atoms, seeds.

Atomists

Rubbish

Leucippus fl. c. 475 BC.
Democritus c. 470 – c. 410 BC.

Socrates (470–399 BC.)

Plato (427–347 BC.) (dist. – Worldliness of Forms & Ideas – Reality)

Cosmogony discussed in Timaeus
– Mathematical atomism
Founded the Academy.

Post-Plato

3 main Schools

Epicurus (342–270 BC.) followed atomism
↳ Lucretius (c. 95–55 BC.)

Stoics (believed in the Cartesians)

Aristotle (384–322 B.C.) the Peripatetics
↳ dominated Scholastic Rhetoric, and science down the Copernicus & Galileo –
– worked with Christian theology

Left Athens shortly before his death
when indicted for 'impiety'.
"Athens should not sin twice against
Philosophy".

2, St Thomas Aquinas (1225-1274 AD).
(and by Averroes (1126-1198 AD) with Islam)
I shall concentrate on

Aristotle (384 BC - 322 BC) born in Stagira
Studied under Plato until Plato's death in
Tutor to Alexander the Great.
Founded the Peripatetic School.
(with Lyceum)

Main Works

Organon : Books on Logic
(Instrument of thought)
Posterior Analytics (Deductive Method)
First principles induced from experience by intuition. Bk II ch. 19.

Philosophy — The Metaphysics
matter & form.
doctrine of potentiality

Physical Science

change in general — The Physics (Physica)
locomotion in heavens & on earth — On the Heavens (De Caelo)
qualitative change — On Coming-to-be & Passing-away (De Generatione et Corruptione)
Forced change? in the atmosphere — Meteorology (Meteorologica)

+ Biology, Psychology, ethics, politics etc.
Collected works ed. Ross.

See also G. Lloyd: Aristotle: The Growth & Structure of his Thought

and the same
W. Jaeger: Aristotle: Fundamentals of the history of his Development
(gradual shift away from Plato)

Standard Greek edition by Bekker:
130a 12 means line 12 of two column a of p. 130 of Bekker edition

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Metaphysics concerned with Being
See. Met IV ch 1, 1003a 17
(p731)

Physics concerned with change through 'nature'
– essential change (this does not mean change in essence)
N.B. Aristotle is concerned with observation, not with experiment

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Books cited
Neugebauer (3 Vols) : Astronomy in Antiquity

Commentaries by Ross: Aristotle

and Solmsen: Aristotle's System of the Physical World

See also chapter on Aristotle in

S. Sambursky: The Physical World of the Greeks.

and Cohen & Drabkin A Source Book of Greek Science

Aristotle's Physics is very much concerned with change (~~a movement~~ in a ~~general sense~~)

3 sorts of ~~Movement~~ change

① Coming-to-be and ② passing-away and ③ movement (or process) ~~alteration in quality~~

~~Local motion (change in place — also change in size)~~

Aristotle is opposed to Parmenides (Nothing changes because change involves 'what is' coming from what is not, and how can 'what is not' be the 'source or ground of 'what is'.)

He is also opposed to the atomist doctrine in which particles do not change but only

cf Phys p. 81

Motion as an actualization of that which is potential, as such is. If there is something which is actually x and potentially y, motion is the making actual of y-ness

* 3 types of Movement:

alteration as quality / change in quantity (size)
or place (locomotion)

N.B. A. after, less Movement to include generation / destruction and as general means of alteration changes in accidental qualities, not substantial / essential change, which to would denote as generation / corruption.

spatial arrangement. In particular Aristotle denies ~~the~~ 'void' (see below)

Aristotle's solution to the problem of change is as follows:

Substance = Matter + Form.

(Prime) matter is potentially of form as matter acquires form it becomes a determinate, differentiated 'this' i.e. it becomes not potential substance but actual substance.

Change = Fixed matter + changing Form.

Forms or attributes are either essential, man is a rational animal

or accidental, John is a musician

change is either ~~[illegible]~~ essential (i.e. in virtue of something's nature)

*movement or process { ← generation Form comes into being. ~~alteration~~ . ~~essential~~ form changes (contrary) corruption or decay Form disappears. (contradictory)

~~But~~
or change is accidental
John starts playing the trumpet

But not-being is not a difficulty since forms are present potentially

note earth → fire is generator
because cold is = privation of hotness

The acorn is potentially the oak tree

The Musician can potentially play the trumpet and so on.

This doctrine of { matter and form / Potentially + actually

is explained in the Metaphysics (Bk 9)

Aristotle wants now to examine what produces change (or movement or motion in the generalized sense)

He explains in the Physics his doctrine of the 4 Causes (Physics BK II ch. 3.)

Eg Statue

1) material — marble
2.) Formal — shape
3) efficient — chisel
4.) Final — production of a work of art.

→ Teleology.

In his chemistry Aristotle argues that ~~the supposed~~ clean elements earth air fire and water can change into one another, because each doesn't contain forms, which can come and go

Thus ~~fire~~ Earth = cold + dry
air = hot + fluid
Fire = hot + dry
water = cold + fluid

In regard to local movement (our ordinary idea of motion) Aristotle develops a theory of, space and time

Space and time are continuous. i.e. infinitely divisible so indeed is matter (as against the atomists) but the total universe is finite in extent and quantity of matter.

This is because ∞ divisibility = potential infinity

which A. allows
but ∞ extent & quantity would be a completed infinity which A does not allow

But Time is ∞ in both directions since all instants do not coexist this is not an example of completed infinity. (Conflict with theology of Plato universe is created (Timaeus))

Aristotle's Cosmology

Crystalline spheres carry planets round a spherical stationary earth. (Borrowed from Eudoxus, but now taken literally)
Perfect motion is circular
Natural to aether, the 5th element of which the stars are made.

[illegible] 55 spheres in all (Metaphysics Bk 12 ch 8) (p. 883)

In sublunary region we get change and decay and different laws

cf. Newton

Mass × Acceleration = − Force − Resistance

N.B. Aristotle does not say
a heavy body in the void
would move faster than a
lighter body
in the void they all move
at the same speed

See p. 236
Physics Bk II, ch 1.

N.B. If a body is thrown it experiences friction because of action of air (which also causes resistance) it is a big problem in practice! (cf 2nd is looked for in notes)
Physics Bk II ch 8 (p. 254)

Natural motion too is in st. line. earth goes towards centre fire goes away from centre.

But natural motion can be perturbed by force or unnatural motion and [illegible] motion of the projectile.

Aristotle's Law of Motion (Physics Bk IV ch 8 (p 284) But cf. Bk VII ch 4 (p. 353) measures force required)

Velocity = Force / Resistance

(cf. Acc = Force - Resistance)

If resistance → 0, Vel. becomes infinite.

This is one of A's powerful arguments against the void.

For A. explanation in science is to identify the 'nature' or substantial form of a body and the destiny that Nature will endeavour to fulfil.

But every property of of a body, magnetic extent e.g. becomes in scholastic development of Aristotle. endowed with its own form.

Explanation in terms of form becomes circular.

cf Opium causes sleep in virtue of a dormative principle (or form)

But only evidence for this power is the accident it produces.

Additional points , Physics Bk II Part C

A - Belief in chance denies fatalism of argument of the sea-battle. in De Interpretatione ch. 9.

~~Sea battle will occur or~~
Sea battle will occur or not occur.

Does this mean that that the battle will occur or will not occur.
i.e. is the occurrence or non-occurrence of the sea-battle determined as well as determinate

B The Unmoved Mover (God) is source of the motion of the outermost sphere.
Physics Bk 8.

Other spheres are moved by 'intelligences' (angels?) Relation to the Primum Mobile not at all clear in Aristotle.

Mechanics after Aristotle

Contribution to Statics by Archimedes (the greatest of all the Greek scientists and mathematicians.

Contribution by Archimedes (c.287 - 212 B.C) (Syracuse)

1.) Theory of the lever in 'On the Equilibrium of Planes'.
2) Archimedes Principle, or hydrostatics — theory of the floating, buoyancy 'On Floating Bodies'
3.) Method of Exhaustion — anticipation of the integral calculus. (Doctrine of limits)
4) Practical inventions Archimedes screw war machines etc.
5.) Notation for very large numbers The Sand Reckoner.

The Alexandrian School — Euclid (c. 330 - 260 BC), Apollonius (c 220 BC) — Conic Sections

Hero (A.D. 62) (simple form of steam turbine)

Ptolemy (c. A.D. 140) (The Almagest) — culmination of Greek astronomy. Following are laws:

The Poetics

Lucretius 'On The Nature of Things' (c. 15-55 BC) Epicurean Epic

Pliny (23-79 A.D) Natural History in 37 Books - First Universal Treatise of Science & Technology

Heracleides of Pontus (c. 388–315 BC) rotation of earth
⇓
Aristarchus (of Samos) (c 310–230 BC)
Heliocentric theory — taught at Alexandria.

Hipparchus (c. 190–120 BC)
discovered precession of the equinoxes

cf also
Eratosthenes (c. 276–194 BC)
estimated size of the earth
— really a geographer. (but also a mathematician — cf Sieve for prime numbers)

The Dark Ages 500 A.D. – 1000 A.D.

Greek manuscripts preserved in Byzantine Empire (the Eastern empire)

But classical Greek is quite different from Byzantine Greek!

The culture not really transmitted to the West until conquest of Constantinople by the Ottoman Turks in 1453.

In Europe Greek philosophy, science at second or third hand, Latin commentaries or Encyclopaedias (cf Venerable Bede)

The Greek Texts of Aristotle came to the West in 11th–12th Centuries by translation from the Arabic.

Arabic Science translated Aristotle into Arabic:

Averroës, Spanish Moor (1126–1198) known as the Commentator

cf. also Avicenna Persian (Islam) (980–1037) philosopher, physician

Other major figures, particularly in Optics

Alhazen (965–1038) (developed the idea of if)

Al Kindi (813–880)

Abu Albiruni (973–1048), whose astronomical works have still not been translated (cf Ramjidipour at Chicago).

Arabic texts became known in the West after the defeat of the Spanish Moors, resulted in the great explosion of translation of the philosophical & physical treatises of Aristotle.

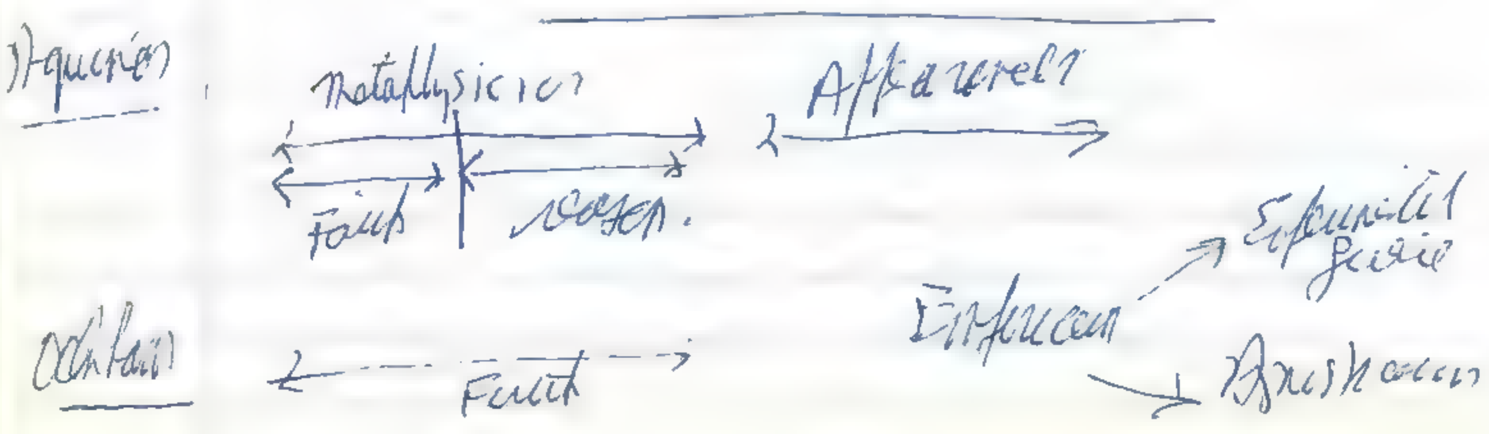
Practical Discoveries in the Middle Ages

1.) Lenses
2.) Compass.
3.) Printing.
4.) Clocks (escapement)
5.) Gunpowder & other chemical processes.

~~Aristotle~~ Aquinas allows some knowledge 'beyond appearances' by reason.

Franciscans reject role of reason in theological matters

cf. { Duns Scotus
Roger Bacon
William of Ockham.



The classical literature was not translated in the main until the renaissance (15th) 16th century).

Also Archimedes was not translated entirely until the 16th century

13th Century

St Thomas Aquinas (1227–1274) Dominican attempt to reconcile Christian theology and Aristotelian philosophy, where they disagreed faith is to be preferred to reason

Eg. ① Cosmos is created, not existing to −∞.

② Transubstantiation bread, wine are forms without substance → body, blood of Christ.

not founded by Aristotle

ie. form of bread 'disguises' the body of Christ.

③ Nature is regular – no room for miracles

[④ Aristotle also taught that the soul did not survive the body]

Attack on Aristotle

Condemnation of Paris (1277)

To 'prove' anything by philosophy is a constraint on God's power to do anything

Truth can only be known by Faith.

Science should restrict itself to 'appearances'

→ Empiricism ? Nominalism

[Another strand here was emphasis on experiment:

Robert Grosseteste (c.1175–1253)

Roger Bacon (c.1214–1292)]

But the main philosophical route to empiricism was via

William of ~~Occam~~ Ockham (c. 1280–1349).

Nominalist, empiricist, Ockham's razor against 'metaphysical' explanations.

↳ we never know reality beyond appearances except by Faith

cf ~~Nicholas~~ Nicholas of Autrecourt – the medieval Hume. (c. 1300 – c. 1350)

↳ Saving the 'appearances' or 'phenomena'

Science no longer engaged in search for Truth
– no physical reality claimed for alternatives to Aristotle

Here is main continuity with the Scientific Revolution of Copernicus Galileo

Cf. also
Dictionary of Scientific Biography
(ed. C.C. Gillispie)

Medieval Treatises [illegible] usually in the form of Questions interpolated in Commentaries on the works of Aristotle.
Position is advanced then attacked and [illegible] position is then defended (this is the author's own opinion)

Books on Medieval Mechanics

E.J. Dijksterhuis De Mechanisering v.h. Wereldbeeld (1950)

A. Crombie Augustine to Galileo (2 vols.)
Robert Grosseteste and the Origins of Experimental Science (1953)
F. Grant Physical Science in the Middle Ages (1971)

F. Grant Source Book in Medieval Science 1974.

P. Duhem Etudes sur L. de Vinci (1906-1913)
Le Système du Monde (1913-1959) 10 vol.
discussed the Paris 4th C. Ideas emphasized their influence on Scholastics

Now revised reasons by
A. Koyre : Etudes Galiléennes (1939)
a A. Maier : Die Vorläufer Galileis im 14. Jahrhundert (1957)

Marshall Clagett The Science of Mechanics in the Middle Ages (1959)

with translations

D Lindberg (ed.) Science in the Middle Ages (1978)
15 essays on Medieval Mechanics with many references

ch adv E. Grant — Much Ado about Nothing : Theories of Space and Universe from the Middle Ages to the Scientific Revolution.
C.U.P. (1981)

A. Franklin The Principle of Inertia in the Middle Ages, 1976. (cf. also Am. J. Phys. 44 (1976) 529.)

cf. two articles:

F. Grant Isis, 55 (1964) 265
'Motion in the Void and the Principle of Inertia in the Middle Ages'.

E. Moody J. Hist. Ideas 12 (1951) 163, 375
'Galileo and Avempace: The dynamics of the Leaning Tower Experiment'.

Medieval Dynamics

Aristotle $V = k\, F/R$, $F > R$ assumed

Motion requires both force, contact

John Philoponus (6th c. A.D) and Avempace (12th c. A.D) replace with

$$V = k\,(F - R)$$

Hence motion in a vacuum becomes possible

Thomas Bradwardine ~~$V = k \ln F/R$~~ ($F > R$?)

$$V = V_1 \log_a F/R$$

where $a = F_1/R_1$ ($F_1 > R_1$)

i.e. $\left(\frac{F_1}{R_1}\right)^{V_2/V_1} = \frac{F_2}{R_2}$

Note $V = 0$ for $F = R$ in Bradwardine's Law

The Concept of Impetus

John Philoponus rejected the role of air in projectile motion — we cannot move stone by agitating air behind it — introduced an 'incorporeal motive force'.

developed by
Avicenna (*mail* = inclination or tendency)

led to work of (c.1295 – c.1358)
John Buridan introduced term *impetus*

impetus = mass × vel.
But impetus is *cause* of motion not *effect* of motion, so it is *not* momentum

Buridan also explained accelerated motion of free fall by successive acquisition of increments of impetus

gravity produces vel. + impetus
↳ more velocity
and so on

Buridan again uses infinite motion in a void as argument against the void — impetus is *not* dissipated (if unresisted)

cf doctrine of *transient impetus* due to *Nicholas Bonetus* (died c.1343)

Medieval Kinematics (The Intension & Remission of Forms / Qualities)

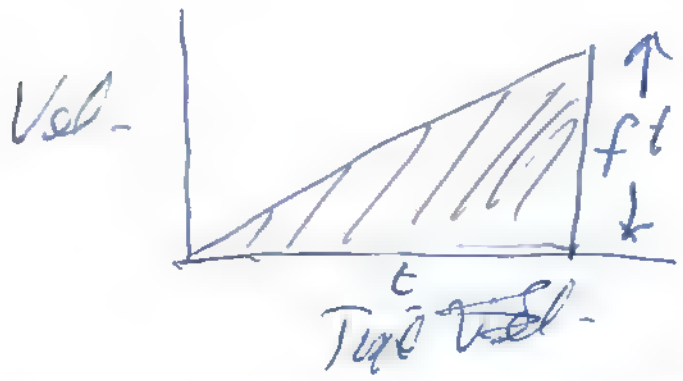
The Merton School:

William Heytesbury, John Dumbleton, Richard Swineshead

Thomas Bradwardine. (Master of Merton College 1328–1350)
Archbishop of Canterbury

Mean Speed Theorem

$$S \propto v = \tfrac{1}{2} ft^2 = \underbrace{\tfrac{1}{2}(ft)}_{\text{mean speed}} \times t.$$



S = area of Δ. $= \tfrac{1}{2}(ft) \cdot t.$

Also Treated by:

Nicole Oresme (c 1320 – 1382)

'On the Configurations of Qualities'

Glossary of Astronomical Terms

Zenith — Pole of horizon system

Altitude and Azimuth (horizon system)

Declination and right ascension (equatorial system)

celestial latitude and longitude (ecliptic system)

ephemerides — elements of a planetary motion

apogee, perigee — farthest from earth, nearest to earth

Motion { diurnal daily; annual yearly; secular slow or episodic }

aphelion, perihelion — farthest from sun, nearest to sun

apsis of orbit

line of apsides joins apogee and perigee

nodes intersection of orbit with ecliptic

syzygy object earth and sun in opposition or conjunction (i.e. on a st. line)

quadrature object at rt. angle to earth-sun line.

Ecliptic path of sun 23½° to equatorial plane

Zodiac belt in sky 18° wide about the ecliptic, divided into 12 houses or signs, path of the planets (Wandering stars)

Books

J. L. E. Dreyer

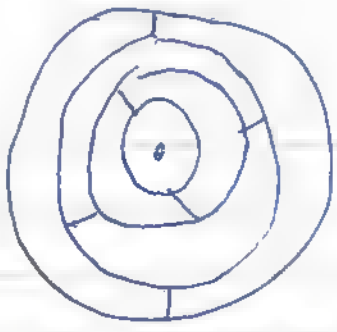
History of Astronomy from Thales to Kepler (1906)

A. Pannekoek: A History of Astronomy (1961)

Sir Thomas Heath - Aristarchus of Samos (1913)

O. Neugebauer (3 vols)
A History of Ancient Mathematical Astronomy (1975)

J. L. E. Dreyer Life of Tycho Brahe, 1890.



Aristotle

Greek Astronomy

~~Two~~ Three main schools:

1) **Homocentric** Earth-centred spheres.
- Eudoxus (c. 408 – 355 B.C.)
- Callippus (c. 330 B.C.)
- Aristotle.

Difficulty does not explain varying brightness of planets, size of moon etc, which suggests heavenly object at 'varying distances from the earth.

(9 bodies = earth, Sun, Moon, 5 planets, fixed stars as sphere) (note 10 = 1+2+3+4 and is a perfect no. for Pythagoreans)

2.) **Heliocentric**

Developed from theories that the earth moves

Philolaus (5th C. B.C. Pythagorean): earth and sun revolve round a central fire (also a counter earth) (10 bodies in all, counteracts; our side of earth always turned away from central fire) (invisible to the earth.)

Rides other side of earth from fire.

Heracleides of Pontus (c.388 – 315 B.C)

Earth rotates also Mercury, Venus go round sun, explains why these planets always close to the sun in the sky. (Sun goes round the earth.)

Op advice Apollonius (c. 220 BC)
Hipparchus (c. 190 – 120 BC.)

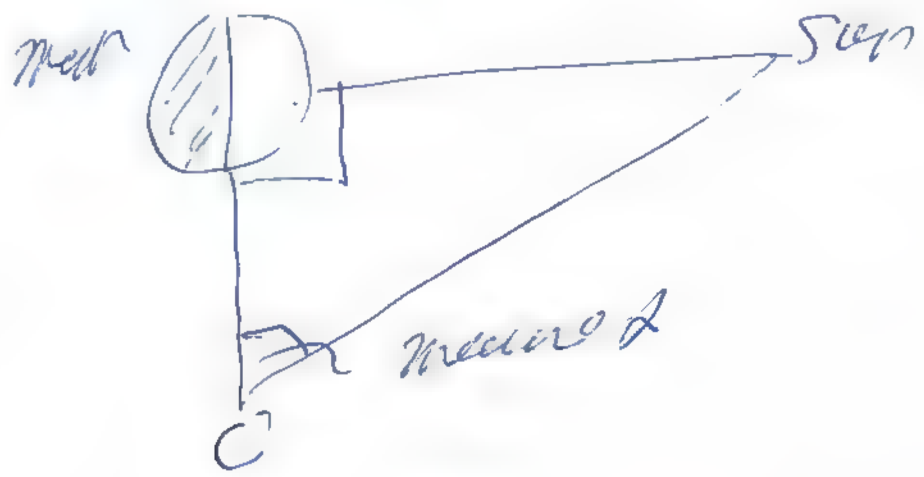
with developed epicyclic theories
and discovered the
precession of the equinoxes
(Hipparchus)

Aristarchus of Samos (c. 310–230 B.C.)

(the 'ancient Copernican')
earth rotates on axis, also goes round the sun.

Main difficulty is absence of stellar parallax & 'dynamical' problems such as Tower Argument.

Aristarchus estimated ratio distances to sun & moon stars



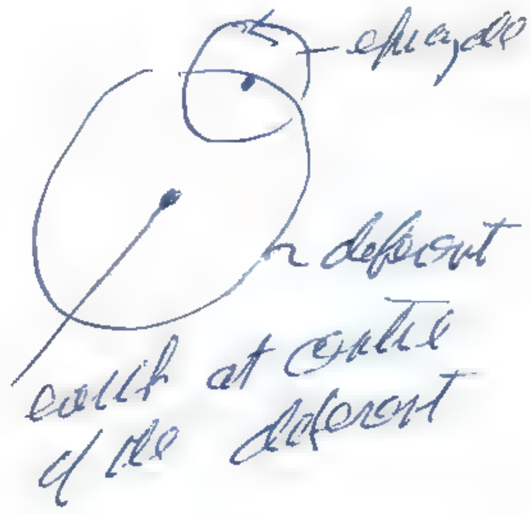
$\frac{OM}{OS} = \cos\alpha$, But α is near to 90° – difficult to measure very accurately.

Aristarchus estimated α = 87° (real 89°52′) – sun/moon = 18 (real 390).

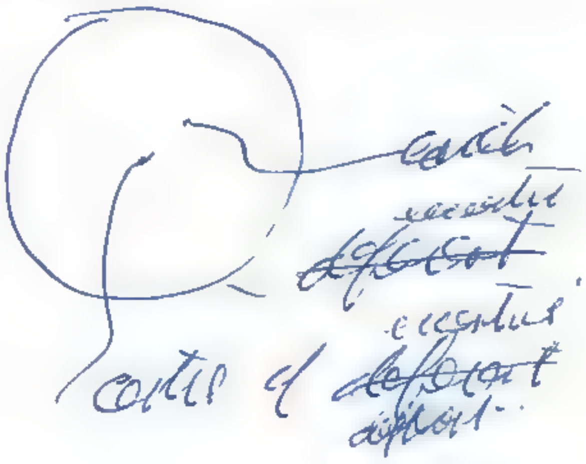
3. Epicyclic theories explain detail of planetary motion, including retrograde motion and varying brightness & speeds of the planets culminating in work of
Claudius Ptolemy (2nd c. A.D.)
who wrote the Almagest

Ptolemy's systems uses 3 main devices

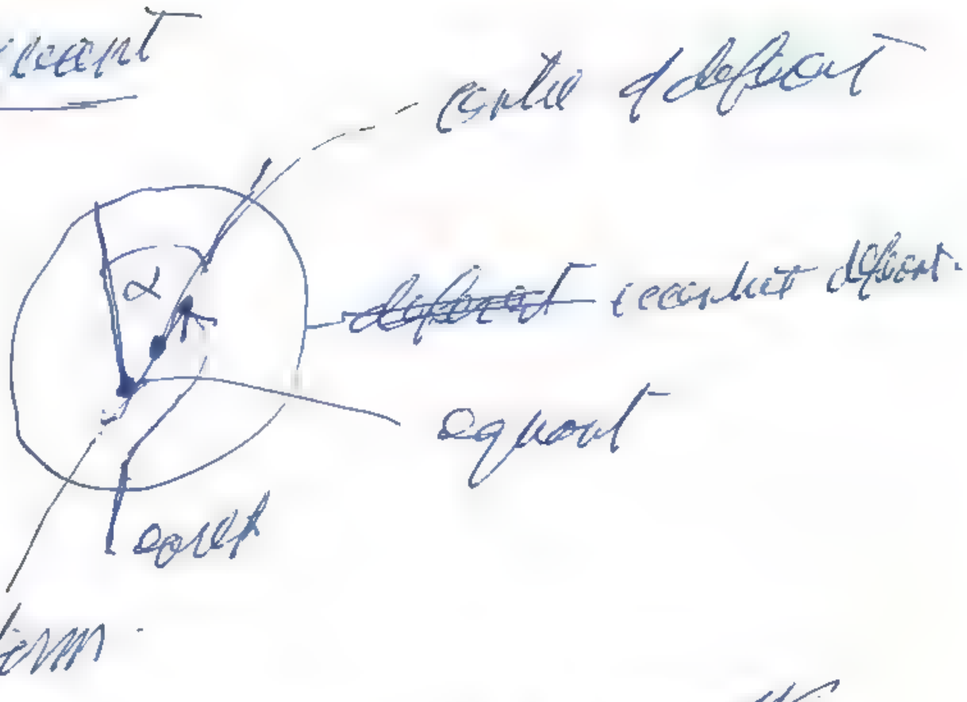
a) The epicycle



b) The eccentric ~~deferent~~ deferent



c) The equant



$\dot{\alpha}$ is uniform.

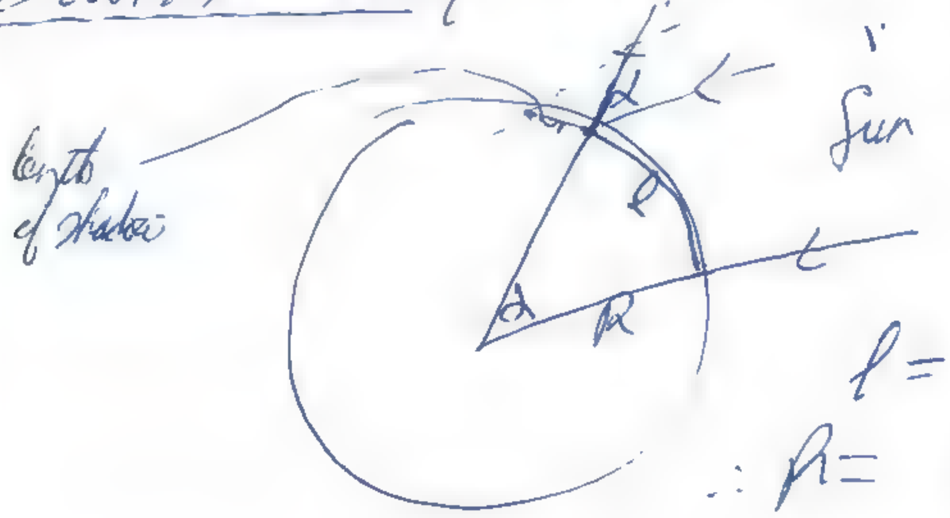
These devices can be combined in various complicated ways.

The figure of the earth

Aristotle and most Greek astronomers accepted that the earth was a sphere.

Reasons:
- horizon
- shape of earth's shadow on the moon
- shape of moon and sun
- sphere 'perfect figure'.

Estimate of size of the earth by **Eratosthenes** (c. 276–194 B.C.)



$$l = R\alpha$$

$$\therefore R = l/\alpha.$$

N.B. in the Middle Ages everyone accepted earth was round.
Argument for Columbus was then: how long is the earth i.e. how long to sail to the Indies by the westward route.

Medieval astronomy.

followed Ptolemy.

15 century Georg Peuerbach and his student Johannes Müller (Regiomontanus)

based their work directly on the Almagest -

But in 14th century idea that earth turns was mooted, particularly by (rotation of earth within Buridan and by (dept of [illegible]) Nicole Oresme (c.1320-1382)

- deals with the Tower argument by reason of Galilean relativity: air carried round by earth objects share motion of the air. Notion of (circular) inertia not really present until Galileo.

Also plurality of worlds was argued for as possible by Oresme, Buridan & Albert of Saxony

and an infinite universe by

Nicholas of Cusa (Cusanus)

- forerunner of Thomas Digges and Giordano Bruno in the 16th C.

Books on the Scientific Revolution:

* A. C. Debus: Man, Nature and Renaissance (1978)

F A. Burtt: The Metaphysical Foundations of Modern Physical Science (1932) rev. ed

H. Butterfield The Origins of Modern Science (1952)

Marie Boas The Scientific Renaissance (1450–1650) (1962)

* R.S. Westfall The Construction of Modern Science (1971) many Dutch ed.

A.R. Hall The Scientific Revolution (1500–1800) (1954) 2nd ed 1962.

→ The Revolution in Science 1500–1750 (1983)

A.R. Hall From Galileo to Newton 1630–1720 (1963)

Penel & Marie Boas' bk

The Renaissance

In Art, literature the R. dates from 13th Century.

Rediscovery of Greek texts and learning to read Greek itself.

↳ Respect for the ancients

But 3 other factors:

1) 16th C translation & appreciation of Archimedes led to example of how to do mathematical physics

Also renewal of Neo-Platonism & number-mysticism clearly seen as influence in Kepler.

2.) A new sense of using reason and observation to get at the truth or reality behind the appearances - rejection of 14th C strict empiricism made science possible again.

3.) Respect for texts more ancient than the Greeks.
— Hermes, the Hermetic literature
(Trismegistus) - legendary Egyptian alchemist
↳ Rosicrucians, the study of alchemy etc
— the rediscovery of an ancient wisdom lost even to the Greeks

"Scientific" these two themes : reason, mathematics & observation

"Mystical" and Mysticism, Natural Magic, Alchemy, etc.

On the other are most characteristic of the period 1450–1650

In some cases, e.g. Newton the two interests are indeed combined.

The first theme led to Modern science; second petered out ~~towards~~ in the 18th Century.

End of Mystical approach

John Dee
Robert Fludd
Paracelsus. (Philippus Aureolus Bombastus von Hohenheim).

Books

A. Koestler The Sleepwalkers
deals with Copernicus Kepler (his hero)
& Galileo — rather unfair to Galileo

T. Kuhn The Copernican Revolution

A. Armitage Copernicus

Translations of De Revolutionibus:

Duncan (colloquial)
Rosen (1978) not scholarly.

Others: E. Rosen: 3 Copernican Treatises:

The { Commentariolus
{ Letter against Werner
{ Narratio Prima

support of ancient observations which had been challenged by Werner

Nicolaus Copernicus (Niklas Koppernigk) (1473 - 1543)

born in Torun in Poland.

Studied in Italy at Bologna, Padua, Ferrara

returned as Catholic Canon in 1506

to | in Ermland. (Canon of Frauenburg Cathedral)

His heliocentric system was not published until the year of his death

1512 | Preliminary manuscript: De Commentariolus describes system in broad outline.

Persuaded to publish De Revolutionibus Orbium Coelestium

by his disciple, Georg Joachim Rheticus, who came to study under him in 1539.

Rheticus published De Narratio Prima in 1540

, again an introductory account of the complete system.

Rheticus returned to Nurnberg to supervise the publication of de Revolutionibus but was called to a chair in Leipzig and the final editor was Andreas Osiander who contributed a famous preface, claiming that Copernicus' system was just another way of saving the phenomena not to be taken in a realistic sense

Summary of De Revolutionibus (6 Books)

Osiander's Introduction.
'For it is necessary that these hypotheses should be true, nor indeed even probable, but it is sufficient if they merely produce calculations which agree with the observations'.

Preface: To his Holiness Pope Paul III.

C says he will be 'hooted off the stage' for his opinions (explains his delay in publication?)

C says he was influenced by the disagreements among the ancients, homocentrics, epicycles eccentrics etc — then refers to 'Philolaus Heraclides and Ecphantus [who] believed the earth moves.
— (quote from Plutarch)

Book 1

d 1. Universe is spherical — perfect or most capacious shape

2 Earth is spherical: brings phenomena rising & setting of stars 'causes' with latitude etc.

3. How water & the earth — explains dry land! earth can likely be dry apart says rather.

4 Motion of heavenly bodies is uniform (and perpetual), or compounded of such motions — rejection of the equant.

5. Circular motion also proper to the earth rotation + planetary motion

§6. The immensity of the heavens as compared with the size of the earth.
— parallax argument — not used.
— observed that stars revolve every 24 hours.
(says horizon bisects celestial sphere — compare argument of Ptol.)

7. Why the ancients said the earth was at rest.

a) earth falls to the centre because it is heavy
(b) — former argument.
(c) [Outward wind] etc. → (motion of clouds) as [illegible] actually used by C.
(d) earth would fly asunder

8. Refutation of these arguments — i.e. earth may rotate, circular motion is natural, air also rotates.
Heavy things think they are at rest.
Natural motion of earth was not disintegrate it — What about stars if they revolve would not whole universe fly apart?

9. On several motions for the earth, i.e. is it a planet? Where is the centre of the universe? The Sun

C says gravity [illegible] into globular form — planets as well as earth (not only rotation planets however?)

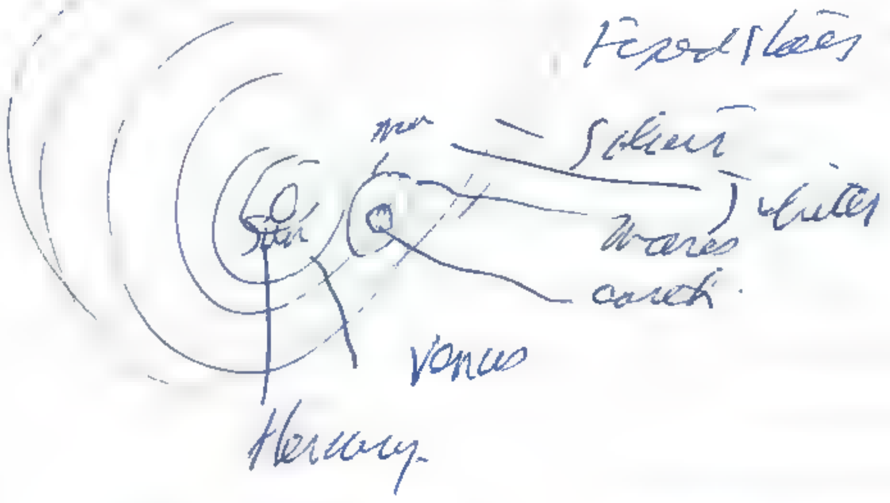
'I myself consider gravity is nothing [but a] certain natural inclination [illegible] which parts are imbued by the architect of all things for gathering themselves into unity and wholeness by assembling into the form of a globe. [illegible] to believe that the sun, moon and other luminaries among the wandering stars have this tendency also so that by its operation they retain the rounded shape in which they reveal themselves but nevertheless go round their orbits in various ways'

Neo platonic attitude to the Sun in Bk10

"In the middle of all is the seat of the Sun. For who in this most beautiful of temples would put this lamp in any other or better place than the one from which it can illuminate everything at the same time? Aptly indeed is he named the Lantern of the Universe by some, by others the Mind, by others the Ruler. Trismegistus called him the Visible God, Sophocles' Electra, the Watcher over all things. Thus indeed the Sun as if seated on a royal throne governs his household of Stars as they circle round him."

But in the detailed theory with eccentrics he found the Sun was not really at the centre.

Ch. 10. The order of the heavenly spheres.



Farthest planets have largest periods

11. The Triple motion of the earth (3rd motion of annual motion of earth)
diurnal, annual and secular.
(non-uniform precession of the equinoxes — but mainly to explain constant direction of earth's axis)

12. ↑ circle diameters, 13, 14 Trigonometry of plane & spherical triangles

Bk 4 i lunar theory
5 Planets in longitude } planetary
6 .. in latitude } motions.

Bk 3 the precession of the equinoxes (earth's 3rd motion) & the annual motion

Bk. 2. General mathematical scheme. of motion of the earth (diurnal only) ~~annual~~.

Translations E. Rosen 1978 (more scholarly)
A.M. Duncan 1976 — Colloquial

Biography : JLE Dreyer : Tycho Brahe (1890).

Major observatory built on Hveen – named Uraniborg.

Instrumental errors reduced by very large size of his instruments.

In 1588 new King of Denmark (Christian IV)

weaned of Tycho's arrogance and expenditure on the upkeep of Uraniborg,

Tycho travelled with his instruments & students looking for a new home and finally settled in Prague.

N.B. In Tychonic system [illegible] about whether Mercury Venus and Mars – cycle [illegible] not possible.

* Cf also Kepler 1600 'Apologia pro Tychone contra Ursum' – Translated in new [illegible] edition of N. Jardine (1984) entitled "The Birth of History and Philosophy of Science"
: Kepler's defence of Tycho against Ursus

(Heavenly Castle)

Tycho Brahe (1546–1601) Danish Astronomer.

left Denmark (Hveen [island], Uraniborg [built]) in 1597 → Prague as Imperial Mathematician in 1599
Carried naked-eye astronomy to the highest possible pitch of accuracy

In 1572 Tycho observed a 'new star' (a supernova).

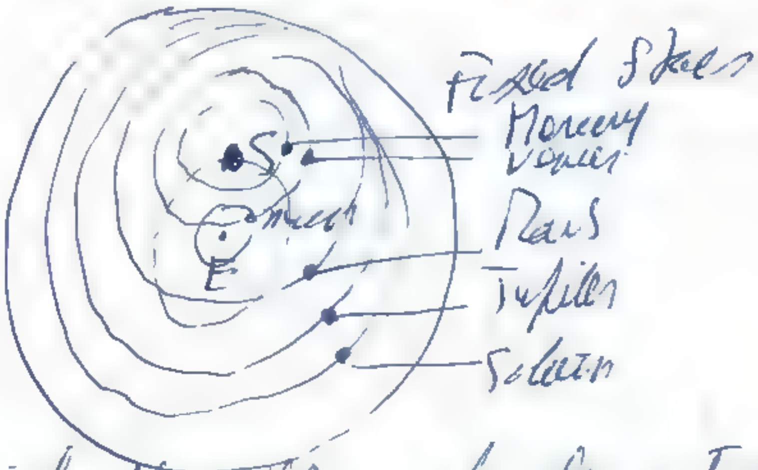
In 1577 Tycho observed the absence of parallax* of a comet and deduced that comets were not sublunary phenomena, but were transient planetary phenomena → change could occur in heavens; also crystalline spheres not possible as comets would have to crash through them.

* parallax due to earth surface not at centre of rotation

The Tychonic system (1588)

5 planets revolve round the sun. But sun and moon revolve round the earth which is stationary at the centre of the sphere of fixed stars

explains why no parallax found for the stars



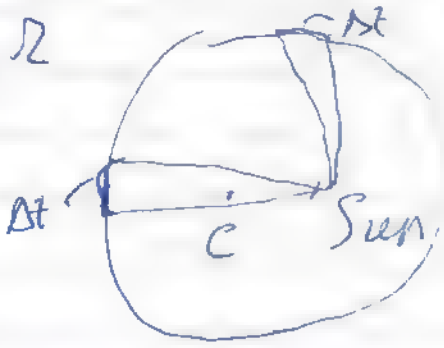
* Argument with Ursus who also introduced this scheme in the same year (probably not a case of plagiarism)

actually $v \propto 1/r$

Discovery of 2nd law

$F \propto 1/r \quad \therefore \quad v \propto F \propto 1/r$

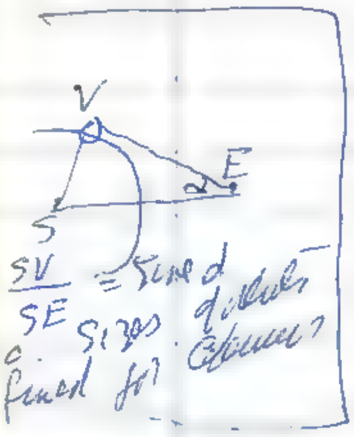
$\therefore \quad \Delta t \propto r$

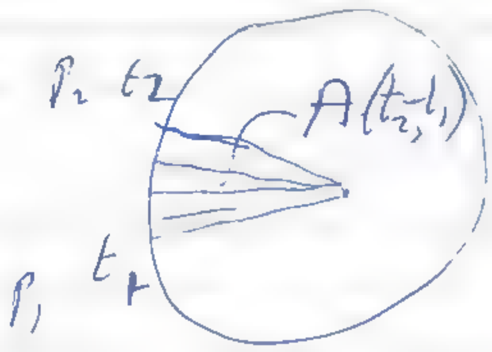


only true at aphelion, perihelion! ∠

then $\text{Area}_{(t_2,t_1)} \propto \sum_{P_1}^{P_2} r$ (!)

$\propto \sum_{P_1}^{P_2} \Delta t = t_2 - t_1$





ie. Area ∝ Time.

Note if ~~$\Delta t \propto r$~~ $v \propto 1/r$ then $T = \frac{2\pi r}{v} \propto r^2 = kr^2$

But this cannot be extended to all planets since the constant k depends on the distance

ie. 3rd law $T \propto R^{3/2}$

Note also for rigid rotation of sphere (with fixed 'spokes') carrying round the planets T = const, so planets must slip backwards in proportion to [illegible] of rotating sphere (Cat[illegible]'s law = 1621)

Kepler also produced work on optics & developed the theory of the telescope being used by Galileo (Dioptrice 1611)

Johannes Kepler (1571 – 1630) b. at Württemberg

Studied under Michael Maestlin (1550-1631) at Tübingen (Ptolemaic theory but Copernican also discussed) — K. became an ardent Copernican and believed by Maestlin

Mysterium Cosmographicum (1596)
K sent copies to Tycho & to Galileo.
Discovered of planets (fixed in the Copernican system, although not with Ptolemaic) given by separation of the 5 regular solids cube, tetrahedron octahedron, dodecahedron and Icosahedron

Kepler worked at Graz (1594-1600) as 'Provincial Mathematician' of Styria
but K. joined Tycho as his assistant in Prague in 1600 → Imperial Mathematician on Tycho's death in 1601 → Linz in 1612.
K. postulated Anima Motrix (cf Gilbert's magnetism) emanating from sun and moving the planets, inverse distance law within plane of the ecliptic, but acting tangentially.

Astronomia Nova (1609) 2nd, 1st laws
of planetary motion stated, 1st law based on careful study of orbit of Mars based on Tycho's observations (discrepancy of 8' of arc)

Harmonices Mundi (1619) 3rd law stated
— Mystical study of musical harmonies for motions of the planets → $T^2 \propto R^3$

Completed Tycho's planetary tables (the Rudolphine Tables) in 1627.

Standard biography of Kepler is
by Max Caspar (1948) Eng. trans. 1959.

See also
C. Hellman - Am. J. Phys 24 (1950) 340-357
"Johannes Kepler's Universe: Its Physics
and Metaphysics"
reprinted in "Historical Essays of
Scientific Thought" (1973)
Kepler to Einstein.

Principal features of Kepler's approach
(cf Dijksterhuis p 322)

1.) Rejection of arguments based on
Tradition, Authority

2.) Independence of Scientific enquiry from
philosophy and theology

3.) Constant application of Mathematical
models of thought to Nature hypotheses

4.) Rigorous testing of geometrical models
against accurate empirical data.

Books on Galileo

A Koyré : Galilean Studies (1978 Trs) & on Platonism

M Clavelin : The Natural Philosophy of Galileo (1974 Trs)

F McMullin : Galileo, Man of Science (1967)

S Drake : Galileo (1980)
and Galileo at work (1978)

D Shapere : Galileo A Philosophical Study (1974)

G de Santillana : The Crime of Galileo (1955)

A Koestler : The Sleepwalkers, Part III.

W. A. Shea : Galileo's Intellectual Revolution (1972)

M Finocchiaro : Galileo & the art of Reasoning (Analysis of Dialogo) 1980

R Butts & J. Pitt (eds) New Perspectives on Galileo (1978)

Galileo's works

S. Drake : Discoveries & Opinions of Galileo (Starry Messenger, Letters on Sunspots, Letter to Christina, & the Assayer) 1957.

Dialogue Concerning the Two Chief World Systems : Ptolemaic, Copernican Tr. Stillman Drake. 1953, rev. ed. 1967 (Ans Salusbury Translation revised by de Santillana 1953)

Dialogues Concerning Two New Sciences Tr. Crew & de Salvio 1914 ed S Drake 1974
(Discourse & Demonstrations Concerning Two New Sciences)

Galileo Galilei (1564 – 1642)

Son of a Musician (Vincenzio Galilei)
born at Pisa, enrolled as a medical student at University of Pisa – left without a degree and continued with private study of Euclid and Archimedes.

1589 chair of Mathematics at Pisa
– Early treatise on motion (de Motu) critical of Aristotle, claimed equal time of fall for bodies of different weight
– apocryphal experiment of dropping weights from Leaning Tower of Pisa

1592 chair of Maths at Padua (Venice)
(more prestigious than Pisa post)

Here he discovered isochronous property of the pendulum, and discussed descent of bodies along arcs & chords of a circle.

1610 The Starry Messenger:
mountains on the moon,
Stars in Milky Way, moons of Jupiter (Medicean stars)

Galileo developed the telescope (discovered in Holland) 1609 – 1610. – After S.M. published he discovered phases of Venus

1610 As a result of fame from Sidereus Nuncius G. resigned his chair at Padua and returned to Florence as Mathematician & Philosopher to Grand Duke of Tuscany (Medici)

1613 Letters on Sunspots
attack on Scheiner for priority in observing sunspots
S. claimed they were planets moving across the face of the Sun.
G. said they were 'defects' on the surface of the sun which were moved by the Sun's rotation. Also explicit support for Copernican system.
1615 Letter to Christina on role of theology in Science.

1616 Pope Paul V made edict that G could not defend the Copernican view

1618 Grassi wrote book on Comets
– attacked by Galileo

1619 Grassi published The Astronomical and Philosophical Balance – attacking Galileo (under pseudonym Lotario Sarsi)
1623 G. replied with Il Saggiatore (The Assayer)
(i.e. the 'finer' balance)

G thought comets were optical illusions
– drew distinction between primary & secondary qualities
– [illegible] polemical work

1632 Dialogo published
upset Pope Urban VIII (Barberini)
who was friendly to Galileo.
Simplicio = Pope ?

1633 Trial of Galileo by inquisition
G. retracts.
Book placed on index
no further publications allowed.
G. sentenced to life imprisonment
— commuted to house arrest.
"Eppur si muove" probably apocryphal

1638 Discorsi published in Holland
(G. was by then blind)

Day 1 Problem of cohesion, continuity, infinity,
2 nature of sound, speed of light etc
— many diversions from main topic of strength of materials

related to vacuum in cohesion → [illegible]

2 strength of materials bending of beams, scale invariance queried!

3. accelerated motion $s = \frac{1}{2} g t^2$
inclined planes, chords ?
arcs of circle etc

4. Parabolic motion of projectiles
(Composition of motions)

Projected 5th day dealing with theory of impact

[speaks for G.] [common sense] [Aristotelian]

<u>Dialogo</u> Salviati, Sagredo, Simplicio

Day 1. Unity of terrestrial and heavenly phenomena.

appearance of moon etc

2. argument for rotation of earth.

relativity of motion & inertia

3. arguments for annual motion of earth
– simplicity of explaining retrograde motion of planets, phases of venus, etc. /

Also motion of sunspots due to inclination of sun's axis to ecliptic.

4. Theory of Tides – main argument for motion of the earth for G.
<u>not</u> due to attraction of moon, but due to acc.) decel. in motion of earth as its rotation then adds to & subtracts from its orbital motion.

<u>But</u> only 1 tide per day?

Also contradicts (in fact?) G's argument that motion could be detected.

Two main events in 17th C Science

1.) Mathematization of Nature
   - not looking for explanations
   - instruments ex. Newton's Principia (1687)

2) Mechanical philosophy, looks for mechanical (i.e. motion, impact) explanations.

Books

R.S. Westfall: Force in Newton's Physics, The Science of Dynamics in the 17th C (1971)

R.S. Westfall: The Construction of Modern Science. Mechanisms & Mechanics 1971.

S. Gaukroger (ed.) Descartes: Physics, Rationalism & Physics (1980)

3 Types of matter
   Primary or subtle matter
   celestial matter (+ secondary matter) Stars / Sun
   Terrestrial matter. (Earth / Planets)

Fluid of primary matter

Rene Descartes (1596–1650) born in Brittany, lived in Holland 1629–1649, died in Sweden. (instructor to Queen Christina)

Discourse on Method (1637) to which are attached Géométrie ~~Geometry~~, La Dioptrique and les ~~Meteora~~ Météores (theory of rainbow)

Géométrie → English translation in 1925.

(Discourse on the method of Rightly Conducting the Reason, Seeking for Truth in the Sciences)

Meditations on the First Philosophy in which the Existence of God and the Distinction between Mind & Body are demonstrated ~~(1646~~ (1642)

The Principles of Philosophy 1644.

D's treatise Le Monde, published posthumously in 1664

Here D described his Mechanical philosophy of world governed by matter (extension) & motion. Afraid to publish because of G's trial.

Main contribution of Descartes

1.) Law of refraction

2.) Law of reflection inverted

3.) M v conserved (wrong)

4.) Discussion of centrifugal force → gravitation

5.) Laws of impact (wrong in most cases) e.g. small body cannot move a larger body.

└ corrected by Huygens

See J. Losee

A Historical Introduction to the Philosophy of Science (1972)

Bacon's 3 analogies

Experiment = The Bee

Rationalist (philosophers) = Spiders who spin webs from their own bodies

Empiricist: The Ant collects matter from flowers and gardens & uses brains to digest it.

Bacon was very influential in 2nd half of 17th C. and Early Royal Society (founded in 1660) was strongly Baconian in outlook.

Francis Bacon (1561 – 1626)

was knighted in 1603, Lord chancellor in 1618
Baron Verulam in 1618 Viscount St Albans
in 1621. Pleading guilty to taking bribes
(never influenced his judgements!)
— Banished from public life.

The Great Instauration

1. The Advancement of learning (1605) — classification of the sciences
2. Novum organum (1620)
(new inductive logic)

New Atlantis (1627) — Imaginary utopian science-based community.

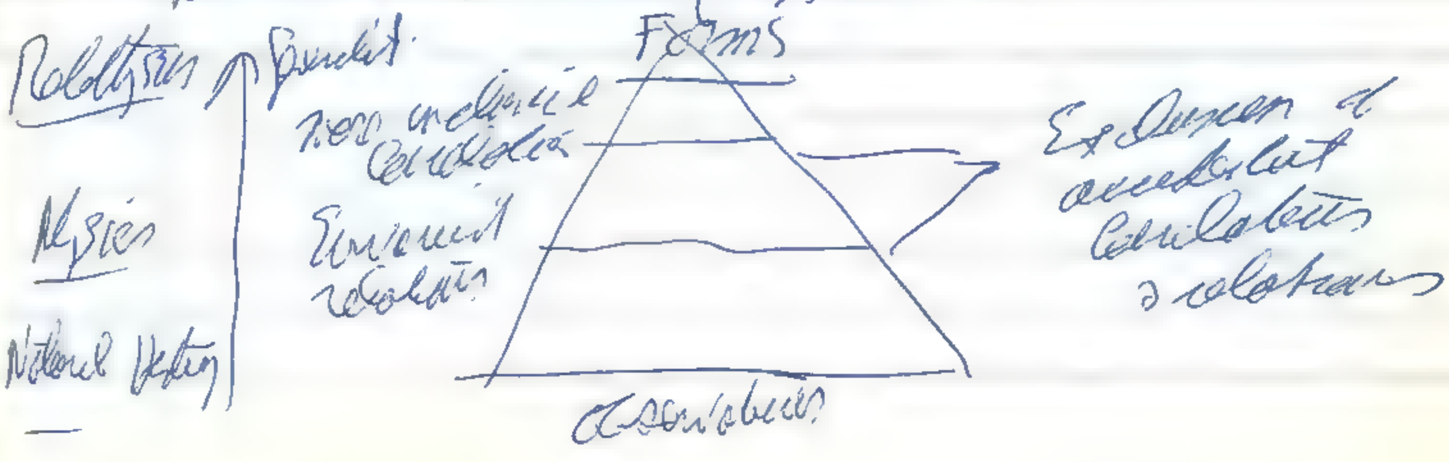
Idols of the Tribe — Too hasty generalizations

Cave — prejudices derived from upbringing, education

Market Place — Vulgar usage of words impeding formation of new scientific concepts

Theatre — Dogmas of philosophical schools, such as Aristotle

Bacon's Ladder of Axioms



not original to Bacon, ←

cp Grosseteste, Ockham, Scotus,
Roger Bacon.

cp Tidal Theory: T_1: Galileo's model
T_2: Rising & falling of sea.

e = correlation of full and ebb tides
across oceans

Tables of Presence

Absence

Degrees

Prerogative Instances of special importance

e.g. Instances of the Finger Post

+ $T_1 \rightarrow e$, $T_2 \rightarrow 2e$ } Crucial experiments

Search for Forms

Ex Form of heat is motion of expanding

↓

Aristotelian vestiges here.

Science has a theological need to discovery — avoid pure doubts

To the metaphysical truths of the forms.

Purpose of science is not knowledge for its own sake but for control over Nature & improvement of Society — co-operative research urged in New Atlantis

New Physiology of the Magnet and of Magnetic Bodies, and of the Big Magnet, the Earth.

Magnetism due to occult specific but electrical attraction due to effluvium

Gilbert's work of the Dutch Hellenic Hermeticism, Natural Magic on the one hand and Empirical Science on the other

William Gilbert (1544–1603)

published De Magnete (1600)
– Magnetic influence not an occult sympathy (detue entar due to effluvium)

Pierre Gassendi (1592–1655) revived
Epicurean Philosophy – more real to Copernicanism.

Syntagma Philosophicum (1658)

Evangelista Torricelli (1608–1647) G's disciple

Blaise Pascal (1623–1662)

Francis Bacon (1561–1626)

De Great Instauration

Novum Organum (1620)

Christian Huygens (1629–1695)

Son of Constantijn H., friend of Descartes

Works <u>De Motu Corporum ex percussione</u> (1656)
(On the motion of bodies in percussion)

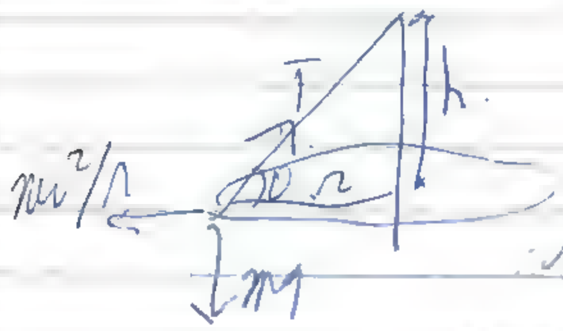
<u>Horologium Oscillatorium</u> 1673, invented the pendulum clock in 1657 (described in <u>Horologium</u> (1658))

<u>Treatise on light</u> 1690

~~expounded in~~ De Vi Centrifuga (1659)

(margin: remained virgin despite the moving earth!) Huygens proved $F = mv^2/r$ → applied to huygens of why bodies are not set thrown off rotating earth and coined term <u>centrifugal</u> force.

Analyzed conical pendulum as a balance of between centrifugal force and tension in the string.



$T\cos\theta = mv^2/r = mr\omega^2$
$T\sin\theta = mg$

$\therefore r \cdot m\omega^2 r / r = mg\cot\theta$

$\therefore \omega = \sqrt{\dfrac{g}{r\tan\theta}} = \sqrt{\dfrac{g}{h}}$

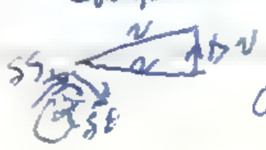
period $= \dfrac{2\pi}{\omega} = 2\pi\sqrt{h/g}$

as $\theta \to 90^\circ$ H. says conical pendulum → simple pendulum with period $2\pi\sqrt{l/g}$.

centrifugal force

note $CD \cdot BC = AC^2$ or $2r \cdot BC = (vt)^2$
$\therefore BC = \frac{1}{2} \cdot \frac{v^2}{r} \cdot t^2$
<u>centrifugal acceleration</u>

cf. modern treatment



$\Delta v = v\,\delta\theta$

$acc = \dfrac{\Delta v}{\delta t} = \dfrac{v\,\delta\theta}{\delta s/v} = \dfrac{v^2}{\delta s/\delta\theta} = v^2/r$

Christiaan Huygens (1629–1695) (believed in the vacuum contra Descartes)

1.) Recognized momentum as a vector.

2.) Correct laws of impact
($\frac{1}{2}mv^2$ conserved as well as mv for elastic impact)

obtained by moving reference frame.
relative to the 'symmetric' center-of-mass collision →← ⇒

3.) Motion of a pendulum, centrifugal force, conical pendulum, compound pendulum.
Recognized cycloidal pendulum as truly isochronous.

– Continued kinematic approach to collision etc

– against any action-at-a-distance

no concept of 'force'.

4) Developed wave theory of light
– pulses rather than periodic motions.

– an explanation of rectilinear propagation and of ~~double refraction~~ polarization

– The Huygens construction

but complete account is given of double refraction

1686 A Brief Demonstration of a Memoir
Error by Descartes' $mv \to mv^2$.

1692 Essay de Dynamique

1695 Specimen Dynamicum (article
in Acta ~~Eruditorum~~
Eruditorum)

Gottfried Wilhelm Leibniz (1646–1716)

child prodigy – prolific writer,
b. in Leipzig, visited Paris where he came under influence of Huygens, became Librarian to the Duke of Brunswick at Hanover from 1676 – death – worked on Brunswick genealogy (visited England in 1673) main rival to Newton at end of 17th C

Contributed to
a) Philosophy
b) Mathematics – the Calculus – priority dispute with Newton
c) Dynamics.

Leibnizian Dynamics

Vis Viva mv^2 is measure of living force – what a moving particle can do (or rather what is done to it).
i.e. to what height it can elevate a body.
cf Vis Mortua dead force as in Statics, but sometimes L. seems to be close to regarding Vis Mortua as potential energy.

Leibniz thinks Vis Viva is conserved – transferred to minute particles in a body but L. does Not say this is apparent as heat.

Also when a ball descends & ascends to same height – its vis viva is preserved totally

(= Vis Viva of the aether?).

as Vis Mortua). These passages about Vis Mortua are rather unclear in Leibniz.
Leibniz never developed a fully worked out dynamics along the lines of Newton.

(mv^2 or mv as measure of force.)

Vis-Viva Controversy lingered on to the middle of 18th C. — then recognised as a verbal dispute

$$\frac{1}{2}mv^2 = \int F\,ds$$ work

$$mv = \int F\,dt$$ impulse.

where F is Newtonian 'Force'.

Leibniz analysed impact in terms of vis viva of parts of the bodies — elastic regarded as bodies part, i.e. dynamical approach as compared with Huygens kinematical approach to impact — also covered ~~elastic~~ inelastic impact.

The Matter is not inert but consists of centres of activity (Monads) — radically contradicting cf the mechanical philosophy.

But note Monads are windowless — they do not interact —, preestablished harmony of different 'perspectives' on reality i.e. each Monad mirrors the universe. It takes account of what all the other Monads are doing.

Books on Newton

H Brougham & E.J. Routh 'Analytical View of Sir I. Newton's Principia', (1855) is a useful expository work.

Never at Rest, A Biography of Isaac Newton
R.S. Westfall (1980)

(Previous biographies by Brewster (1855) & More. (1934))

F. Manuel Portrait of Isaac Newton
— psycho analysis of Newton.

R. Hall Philosophers at War (1980)
(Dispute with Leibniz)

R. Westfall Force in Newton's Physics 1971

J. Herivel The Background to Newton's Principia (1965)

I.B. Cohen Introduction to Newton's Principia (1971)

The Correspondence of Isaac Newton
7 vols. (1959–1977)

The Mathematical Papers of Isaac Newton
8 vols ed. D.T. Whiteside (1967–1980)

Standard Latin ed. of Principia by Cohen & Koyré
(2 vols. 1972)

I.B. Cohen Franklin & Newton (1956)

A.R. & M.B. Hall Unpublished Scientific Papers of Isaac Newton (1962)

I.B. The Newtonian Revolution (1980)

A. Koyré Newtonian Studies (1965)

Newton, Sir Isaac (1642–1727)

– never married

b. Woolsthorpe, lives youthful interest in Mechanical Contrivances, fairy Kites (carrying Lanterns) toy mill powered by a Mouse &c.

Trinity College Cambridge 1661, Graduated BA in 1665.

1665–1666 Cambridge closed because of Plague – Annus Mirabilis for Newton, works on Woolsthorpe on Mathematics, optics, celestial mechanics

"I was in the prime of my age for invention & minded Mathematics & Philosophy more than at any time since"

Episode of falling apple.

1669 appointed Lucasian Prof. of Mathematics (Barrow resigned to make way for Newton).

1672 Made FRS.

1696 left Cambridge to become Warden of the Mint (actually resigned his Cambridge Chair in 1701)

Master in 1700 of Mint

1703 President of the Royal Society (held his until death)

1705 — Knighted

Quarrel with Leibniz (priority dispute over the Calculus, (via Keill) in Commercium Epistolicum report & PRS as the actual inventor, Newton)

five destroyed work on optics (1692) → breakdown in 1693

Tracts on the Calculus

De Analysi — 1669 (published 1711)
(supposedly used by Leibniz)

Methodus Fluxionum et Serierum Infinitarum
— 1671 (published 1736)

Tractatus de Quadratura Curvarum
1676 (published in 1704)

Leibniz first published work on the calculus was in 1684

Certain Published Accounts:
Newton's Trinity Notebook
ed. J.E. McGuire and M. Tammy (1983)

The Optical Papers of Isaac Newton
Vol. 1: The Optical Lectures 1670–1672
ed. A.E. Shapiro (1984)

Also disputes on Alchemy & theology in relation to Science (via. Blake).

Major areas of interest

1.) Mathematics

2.) Mechanics & Astronomy

3.) Optics

4.) Alchemy & Prophecy, Chronology & the Ancient Kingdoms

5.) Scientific Method.

Newton's most innovative use of the study of Physics

Action-at-a-distance rejected in favour Mechanical Explanation.

The Early Newton was more Cartesian. He believed in the Aether to explain refraction & reflection of light, & colours of thin plates.

cp - "An Hypothesis explaining the Properties of Light" - usually referred to as "Hypothesis of Light" — 1675.

- began to introduce 'sociability' in Newtonian particles of Matter & Aether c. 1674.

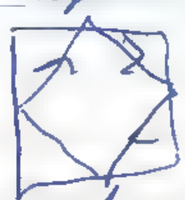
Newton's theory of Colours was submitted to the R.S. in 1672 — provoked much criticism, especially from Robert Hooke — left was modified by the press, not split. — maybe because of Newton was loath to publish for details of criticism.

Force explicitly occurs in Principia (1687) but in the General Scholium to the 2nd ed. Newton gives some ground to the Cartesians in the final para by referring to a possible aetherial mechanism for gravity.
But in query 31 of second English ed. of Opticks (1717) Newton explicitly recognizes action-at-distance in a wide variety of phenomena.
(Part of Queries 17-24 2nd Engl ed. of Opticks)

Newton's Works

1.) Questiones quaedam Philosophicae c. 1664.
[illegible]
45 headings covering most of his later interests and achievements in science
– organization of parts of his readings on matter, place, time, motion, light, colours, fluidity etc.

In 1665-1666 Newton (1) invented the calculus (2) discovered the Binomial theorem (3) did his experiments with the prismatic spectrum# (4) calculated centrifugal force by repeated impact from walls of a polygon in limit as it → circle.



(5) 'apple incident' led to speculation on force of gravity extending to moon.
From Kepler's 3rd law $T^2 \propto R^3$ *
velocity in orbit $= \frac{2\pi R}{T} \propto \frac{R}{T}$
∴ centrifugal force $\propto \frac{v^2}{R} \propto \left(\frac{R}{T}\right)^2 \frac{1}{R} = \frac{R}{T^2} \propto \frac{1}{R^2}$
from *

* other forces than gravity might be acting – a view held by Newton's opponents for a number of years.

So centrifugal ~~tend~~ force on planets ∝ $1/R^2$
If this is balanced by a ~~centrif~~ centripetal force of gravity ⇒ inverse sq. law for gravity.

Newton applied this to the case of the moon.

From period & distance of the moon he ~~estimated to~~ calculated ~~force of gravity~~ ~~of gravity on the moon~~ ~~of the moon towards the earth~~ [centrifugal tendency on the moon] as $\frac{1}{4000}$ × acc. of gravity on earth.

But taking moon's distance as 60 × earth's radius $\left(R_e/R_m\right)^2 = \frac{1}{3,600}$.

So there was a discrepancy *

Actually N. took ~~R~~ R_e from Galileo's Dialogo and is too ~~small~~ large

The problem of attraction of extended spherical earth not solved.

In 1666 N. does not clearly discuss gravitational force as such.
He thinks of circular motion as a static equilibrium (cf Huygens) but does implicitly assume that force of gravity balances the centrifugal tendency.

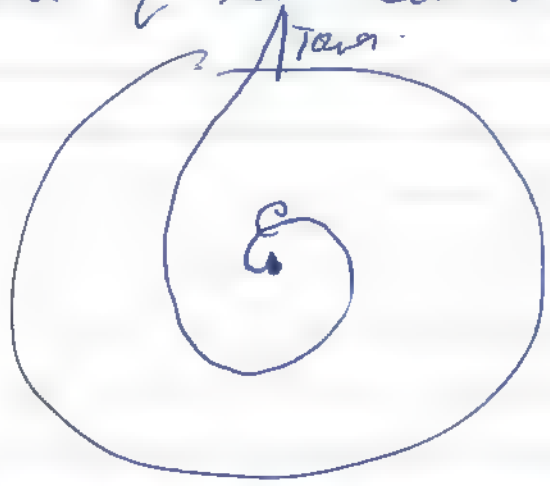
Newton did not return to dynamics until 1679.

Background to the Principia

The idea of universal gravitation was widely discussed in the 1670's by Borelli, Hooke, Wren, Halley &c. Not explicit accounts given by Hooke in his work 'Attempt to prove the Motion of the Earth' in 1674.

In 1679 Hooke, who had succeeded Oldenburg as Secretary of the R.S. wrote to Newton inviting him to resume Correspondence with the R.S. and asking for his opinion on Hooke's hypothesis that planetary motions are compounded of a tangential motion & an attractive force towards the central body.

Newton declined to enter into the Correspondence but in his reply suggested an experiment to prove the rotation of the earth. A body dropped from a great height fell not to the west but to the East and a little North of the point from which it fell.



Hooke replied that it would be a spiral ellipse rather than a circle. The body would fall to the

N.B. Grav field of a sphere solved only in 1685 - by Newton -

Newton replied, agreeing with his error, but said: assuming constant force of gravity that orbit would not be an ellipse.
Hooke replied that this seemed right but he believed inverse sq. law — not constant force of gravity.
Newton did not bother to reply but privately wrote a paper showing that for inverse sq. law path would be an ellipse.

In 1684 Halley visited Newton in Cambridge and specifically asked him what would be the orbit under the inverse sq. law. Newton replied "an ellipse". H. said how do you know? N. said I computed it but could not find his 1679 paper. A few months later N. sent to Halley a short tract de Motu in which Kepler's 1st 2 3rd laws are derived from the inverse sq. law.
The de Motu was revised after ? expanded and in 1687 became

Principia (Philosophiae Naturalis Principia Mathematica)

(2nd ed. 1713 [illegible], 3rd ed. 1726
edited by Roger Cotes / ed. by Henry Pemberton)
English translation by Motte 1729.

Summary of Principia

Newton's Preface to 1st ed.
'I offer this work as the Mathematical principles of philosophy for the whole burden of Philosophy seems to consist in this — from the phenomena of motions to investigate the forces of Nature and then from these forces to demonstrate the other phenomena;

In 2nd ed very short Preface by Newton followed by long Preface by Cotes — main object was to combat the still flourishing Descartes Vortex theory; the Preface advocates 'action at a distance' and that gravity is an innate property of matter (both disowned by Newton afterwards in the General Scholium)
|| For Newton's responses in letters see p. 633/634 Cajori's Notes. See also query 31 in 2nd ed of the Opticks (1717). Cotes preface is also a resounding affirmation of the idea of Universal Gravitation

In 3rd ed; v. short Preface by Newton

Principia starts with
Definitions quantity of matter etc.
punctuated in the Scholium to the definitions
Time, Space — v. famous passages (p.6)
— rotating bucket expts 2 globes joined by a string. etc.
Axioms, or Laws of Motion to 3 Cases

N.B. The Principia does not formally use the calculus (fluxions) but the method of ultimate ratios is employed which is really equivalent to the calculus.

The Mathematical language of the Principia is Geometrical rather than analytical

Book I The Motions of Bodies.

developed in a series of theorems, problems, lemmas, & scholia.

1. orbital motion about a fixed centre.

~~2. the 2-body problem is given a very complete treatment, in particular the inverse sq. law → Kepler's laws. (corrected for unequal finite mass of the Sun)~~

2. the 2-body problem is now discussed (correction to Kepler's 3rd law)

3 In Theorem 24 (Prop. 66) the 3-body problem is tackled. this is the theorem which is later used to discuss a) the perturbations of the moon
b) the theory of the tides
c) the precession of the equinoxes.

4 Theorem 30 (Prop. 70) Newton begins to discuss the vital problem of the attraction of an extended sphere on a particle (outside)
— extended in theorem 42 et seq to the attraction of non-spherical bodies

5.) Book I concludes with discussion of laws of refraction & reflection for corpuscles — application to light appears to be a scholium.

Book II The Motion of Bodies (in resisting mediums)

N. discusses motion of bodies resisted in proportion to v and to v^2.

In Prop. 36 he considers the problem of motion of water thro hole in bottom of a cylindrical vessel, but Newton had no real mastery of hydrodynamics

In Prop 41 & 42 he considers the motion propagated thro' a fluid and shows you cannot have rectilinear propagation.

In Prop 49 he calculates velocity of a pulse in elastic medium

In the scholium to this section N. applies his results to light & sound — light cannot be a wave motion

But vel. of sound does not agree with experiment — N. did not allow for adiabatic compression in a sound wave (cf Laplace's soln of this problem)

But N. fudges the theoretical value for the velocity of sound by an ad hoc allowance for the coarseness of the air particles thro which sound propagates instantaneously.

Finally N. discusses the circular motion of fluids i.e. vortex motion.

In this scholium N. offers a proof that the Cartesian vortex theory of planetary motion — says Kepler's 3rd law cannot be satisfied

" The hypothesis of vortices is utterly irreconcilable with astronomical phenomena, and rather serves to perplex than explain the heavenly motions".

In Bk II N. also describes a number of his own experiments on resistance offered to the pendulum and to falling bodies

(pendulum → in air; falling bodies → in water)

References re Rules of Reasoning

W Kneale: The Philosophy of the Inductive Sciences Vol 2
pp 278-292, 2nd ed (1947)

Rule 1. Vera Causa — may refer to 'familiar causes rather than 'true' causes.

Contd on Rule 2.

R. 3. appear to encourage or to assist a law as universal even where it has not been tried

R. 4 warn that laws may be inaccurate, even where they have been tried

Purpose of rules is to justify tentative generalisations

R.M. Blake, C.J. Ducasse and E.H. Madden 'Theories of Scientific Method' The Renaissance through the 19th Century. (1960)
pp 119-143

E.A. Burtt The Metaphysical Foundations of Modern Physical Science 1st ed. 1924 p. 202 ff.

J. Losee A Historical Introduction to the Philosophy of Science 1st ed. 1972. Ch 8. especially pp. 92-93

J.E. McGuire: "Newton on 'Analogy of Nature'"
St. Hist. Phil. Sci 1 (1970) 3-58

Book III System of the World (in mathematical Treatment)

Rules of Reasoning in Philosophy

1) no more causes than are required to explain phenomena i.e. simplicity in Nature

2.) Same effects have same causes. (used to argue for universal gravitation)

3.) Qualities of bodies always found deemed to be universal — R. induction Analogy of Nature — justified.

N.B. "Not that I affirm gravity to be essential to bodies".

4.) Propositions inferred from phenomena are to be held true until refuted — Conjectures & refutations.

"This rule we must follow, that the argument of induction may not be evaded by hypotheses".

Phenomena. Keplers 2nd & 3rd laws apparently for Jupiters planets Saturn's planets, the 5 primary planets and the moon (2nd law obs.)

N. then deduces a universal law for gravitation & elliptic orbits of planets

N. moves to hypothesis (P. 419)

'the Centre of the System of the world is unmovable'.

In Prop. 19 N. discusses the figure of the earth due to its rotation centrifugal force will cause equatorial bulge – problem not really solved until 18th C. by Clairaut, Laplace etc.
What is equilibrium shape for a sea ~~of uniform depth~~ over a spheroidal earth – condition for sea to be of uniform depth is that earth is also spheroidal.

N. then applies Prop. 66, Bk I to explain
1) lunar motions
2.) tides
3) precession of equinoxes due to action of sun, moon on equatorial bulge.

N. said lunar theory made his head ache.

In Prop. 38 N. discusses the figure of the moon (assumed fluid) and explains ~~what~~ why moon always turns same face to us (modulo libration)

N. then proceeds to give very complete discussion of orbits of the Comets.

N.B. In the Motte translation is included also No. 4. The System of the World which was a preliminary draft of Bk III of Principia with most of the mathematical detail omitted

on p.582 clear discussion of possibility of artificial satellites

→ This is Bk II of de Motu Corporum (1685), a much expanded version of the 9-page 1684 tract de Motu-

General Scholium to the 2nd ed.

'The hypothesis of vortices is pressed with many difficulties

The particular motion of comets is quite unaccountable on vortex theory.

N. argues his theory supports the existence of God.

"This most beautiful system of the sun, planets and comets could only proceed from the counsel and dominion of an intelligent and powerful Being"

God is ~~omni~~ omnipresent substantially'
— (space is sensorium of God)

"Hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses"

i.e. about gravity, not in general?

Final paragraph hints at explanation by "a certain most subtle spirit which pervades and lies hid in all gross bodies"
— i.e. — aether.

NB Hooke died in 1703 then N. felt free to publish? his work on colours?!

Subtitle of Opticks

A treatise of the reflexions, refractions, inflections and colours of light

In 1st ed. N. added two treatises of the Species and Magnitude of curvilinear figures

In N's Advertisement to the 1st ed. he made oblique reference to Leibniz plagiarism w.r.t. the Calculus (p. 122)

In Second ed. Advertisement N
'I do not take gravity to be an essential property of bodies — —

1692 The distressed manuscript of Opticks as it then existed.

cf A.I. Sabra: Theories of light from Descartes to Newton (1967)

G. Cantor: Theories of light in Britain and Ireland 1704–1840

The Opticks   1st ed. (English) 1704 (16 queries)

1st Latin ed. 1706 7 new queries (25–31 2nd English)
2nd English ed. 1717 queries 17–24 in the aether (relation of gravity & electricity to 2nd ed. Principia)
3rd . . 1721
4th . . 1730
↳ brought out after Newton's death with some minor corrections by Newton.

Work on colours one of Newton's major preoccupations throughout his life.
The Opticks is therefore based on much earlier research. Work on experimental physics influence on Franklin etc in 18th c.
Principia terminates the debate of Mechanics
But Opticks marks a new beginning in theory of colours, diffraction, atomic force speculation etc
Opticks in a sense anticipates wave-particle duality thro 'Gready case' that throws confusion into fits of easy reflection and transmission (refraction)
Diffraction and interference colours in thin plates first described by Grimaldi (1665) and Hooke in his Micrographia (1665) respectively, but the latter was much more precisely investigated by Newton (Newton's rings)

N.B. ok at minimum deviation would
stage not be elongated if white
light had a constant refractive index
if decent is taken with differing
angles of incidence on the prism

Book I, Part I

'The design in this book is not to explain the properties of light by hypotheses, but to propose and prove them by reason and experiments'

8 Definitions rays, primary colour associated with homogeneal light (= definite refrangibility)

Continues with 8 Axioms summary elementary laws of reflection & refraction

N. then affirms (Prop 1)

'Light which differs in colour, differs also in degree of refrangibility.'

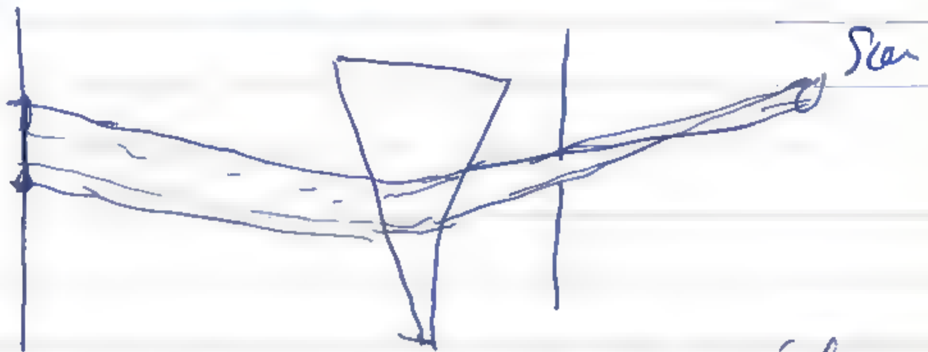
The proof by Experiments

Then follow the famous prism experiments..

image of a small hole in shutter admitting sun light is spread out into an oblong shape i.e. a spectrum is formed

Prop II The light of the Sun consists of Rays differently refrangible

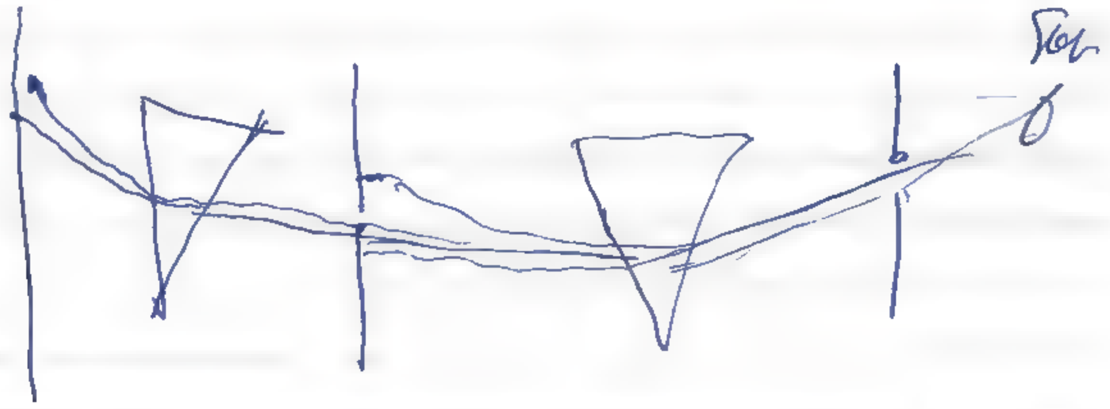
*
Expt. 1



The shape of the image is what surprised Newton

See also Exp 5
with [illegible] [illegible] 45

Expt. 6 is the crucial expt. of using a second prism to refract light from a selected part of the spectrum produced by the 1st prism – No further dispersion is produced



Prop VIII The perfection of telescopes is ~~hindered~~ by the different refrangibility of the rays of light

p102 "Seeing therefore the improvement of telescopes of given lengths by refraction is desperate; I contrived heretofore a perspective by reflexion, using instead of an object-glass a concave metal" → Newtonian reflecting telescope.

Bk 1 Part II This is mainly concerned with mixing of colours to produce white light, the theory of the rainbow and the colours of natural bodies (due to selective reflection.)

N. insists (Prop 1) that colours are not produced by a modification of light as thought by Hooke; others colours were present in white light – revealed by the prism

N.B. Modern theory does not agree with this e.g. Fourier resolution of a pulse

Book II, Part I is concerned with colours of thin transparent bodies (plates)

Here are described the phenomena of Newton's rings.

Book II Part II is entitled

"Remarks upon the foregoing Observations"

emphasises again white as a mixture of colours, immutable relation between colours; degrees of refrangibility — concludes (p. 244) "the Science of Colours becomes a Speculation as truly mathematical as any other part of Opticks"

Book II Part III concerns relationship of permanent colours of objects to colours of thin surface plates in objects — says all substances are transparent — do not reflect light

In Prop 11 N. says light box forte stood — takes 7 or 8 minutes to reach earth from the sun. (refers to Roemer's discoveries of eclipses of satellites of Jupiter.)

Then in Prop 12 N. tries to explain colours in thin plates by his theory of fits. (p. 278) Defined on p. 281

"The returns of the disposition of any Ray to be reflected I will call its Fits of easy Reflexion and those of its disposition to be transmitted its fits of easy Transmission, and the

enhanced by Young - due to large p.d.
no interference effects in white light.
appears like a spurious effect due
to scattering of light at the surface
of the mirror.
cf Mach on Optics. , Brewster's life of Newton

space it passes between every returns & the next returns the Interval of the Fits (so wonderfully)

p. 482 Light is in Fits --- before its incidence on transparent bodies. And probably it is put into ~~these~~ fits at its first emission from luminous bodies!" –

Prop 18 Interval of Fits for yellow/orange light is $\frac{1}{89000}$ inch

Book II Part IV is entitled

Observations concerning the reflexions & colours of thick transparent polished plates –
(cf Fabry-Perot Interferometer or Lummer-Gehrcke plate –)?

Book III observations concerning the ~~inflexions~~ of Rays of light and the colours made thereby.
– refers to Grimaldi's work (on diffraction)

N. proceeds to summarize 11 observations on these phenomena and then on p 338 he breaks off – "When I made the foregoing observations, I designed to repeat most of them with more care and exactness, and to make some new ones for determining the manner

how the rays of light are lost as they pass by bodies for making the ranges of colours that the dark lines between them. But I was then interrupted and cannot now think of looking them into further consideration. And since I have not finished this part of the design, I shall conclude with proposing only some queries, in order to a further search to be made by others.

Queries

1. Do not Bodies act upon light at a distance, and bend the rays.

2. Do not rays of different refrangibility differ in their recess from those bodies.

5. Do not bodies & light act mutually — bodies to emit reflect, refract, & reflect light, & light heat bodies and put the parts into a vibrating motion wherein heat consists.

8. Do not all fix'd bodies when heated emit light, and to the vibrating motion of their parts

9. Do not fire a body heated so hot as to emit light

12. Do rays of light fall on the eye excite vibrations in the retina.

13 are not sensations of colour similar to sensations to sound

14. Harmony & discord of colours compared with the case of sounds.

Query 17 introduces aether ideas

17. When a ray of light falls on the surface of a pellucid body may not waves & vibrations or tremors be excited in the reflecting or refracting medium. These vibrations overtake the rays of light and put them into the "appropriate Fits. the rays are alternately accelerated and retarded by the vibrations overtaking them".

18. Introduces a subtler medium than air to account for these vibrations — the aether

20 Aetherial medium extends beyond bodies so refraction takes place gradually. — also produces diffraction phenomena.

21 Is not the aether the cause of gravity?

22 Is not the resistance offered by the aether to planets & comets negligible

23 Are not aetherial vibrations propagated thro the optic nerves to cause vision

Received 20 Bartholomies (Erasmus)
1669